Geosynthetic cementitious composite mats - Essential characteristics and properties

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ABSTRACT: Geosynthetic cementitious composite mats (GCCM's) were originally developed in 2005 and are a relatively new material technology in the world of geosynthetics. GCCM's consist of a flexible 3-dimensional fibre matrix filled with a high-early strength dry concrete mix with a polymeric membrane laminated onto one side. In this way they combine geotextile, geomembrane and concrete technology enabling geosynthetics to be used in completely new markets and applications.
GCCM's have continually been advanced over the last 12 years, improving performance, quality and scope of application. This paper is an overview of the latest developments to characterize the properties of this new class of material. Specifically, it will focus on the essential characteristics of GCCMs which are being integrated into an EAD (European Assessment Document) for GCCMs:

- Thickness & density
- Flexural strength
- Abrasion Resistance
- Puncture Resistance
- Durability

Keywords: (flexural strength, cementitious, composite, GCCM, concrete canvas, puncture, durability)

1 INTRODUCTION

GCCMs are a relatively recent development within the world of geosynthetics and are fast becoming a popular alternative to conventional concrete construction for a wide range of erosion control applications such as channel lining, slope protection, culvert lining, remediation, bund lining and weed suppression. Typically, GCCMs are used as an alternative to conventional concrete techniques such as poured, sprayed or precast concrete and rather than displacing existing geosynthetic materials they are increasingly being used in combination with them to form part of the complete solution, for example as the protective facing for a geogrid reinforced soil wall.

GCCMs are flexible prior to hydration and set hard on the addition of water to form a thin, durable, waterproof concrete surface. They consist of a three-dimensional fibre matrix filled with a high early strength cementitious powder mix. Once unrolled and fixed in position they can be hydrated by spraying with water and typically set to 80% full strength within 24 hours from initial hydration and are then ready to use.

The relatively recent arrival of GCCMs to the geosynthetics industry has meant that their material properties and appropriate test methods are still being developed and defined. There is therefore a lot of new test data as well as new standards which this paper will seek to introduce and discuss. By way of an example a new ASTM standard (D8058) that defines the flexural test method for assessing the performance of GCCM materials was recently approved for publication. This provides a 'benchmark' test for this new class of material, in much the same way as tensile testing has long been used as an index test for other geosynthetics such as geogrids or geomembranes.

1.1 *GCCM construction*

The new ASTM D8058 defines GCCMs as *'a factory-assembled geosynthetic composite consisting of a cementitious layer contained within a layer or layers of geosynthetic materials that becomes hardened when hydrated'*. The material construction consists of 3 layers:

- A hydrophilic fibrous top layer (typically polyester)
- A 3-dimensional fibre reinforcing matrix filled with a specially formulated dry, high early strength cementitious blend
- A low permeability polymeric bottom layer (typically PVC)

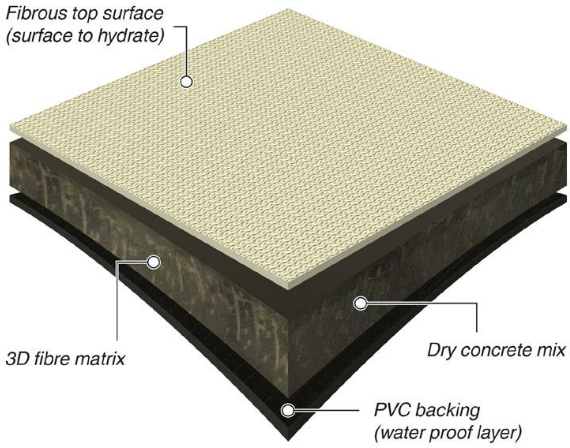

Figure 1. Section of a GCCM.

The layers perform the following functions:

- The polyester top layer acts to contain the dry powder mix during transportation and aids hydration on deployment by wicking water into the material and underlying cementitious fill. Once set the fibrous top layer allows the surface to 'green-up' by supporting non-root growing vegetation such as lichen and moss growth.
- The 3-dimensional fibre matrix controls the material thickness and acts to prevent dry powder dislocation during transport and prevents slump on hydration. Once set the fibres act to prevent crack propagation and provide a 'semi-ductile' safe failure mode.
- The high early strength concrete mix within the fibre matrix sets on hydration to form a hard-wearing, chemically resistant, durable core providing the material with its structural rigidity and protective capability.
- The polymeric bottom layer acts to contain the dry powder mix during transportation and aids hydration by preventing the hydration water from seeping through the material and into the underlying substrate. Once set, the polymeric backing provides a low permeability liner, which in addition to the set concrete acts to provide a waterproof layer. Reinforcement fibres within the polymeric layer provide additional tensile capacity to the material, typically with a higher stiffness than the polymeric backing, they protect against rupture when loaded in bending in field conditions.

1.2 *GCCM hydration*

A GCCM is typically unrolled and fixed in position in the same way as a conventional geosynthetic. Once in position it can be hydrated by spraying with water or through full immersion. A minimum water requirement is approximately 50% by weight, for example a 7kg/sqm GCCM will require a minimum of 3.5lt/sqm. However, for practical reasons it is preferred to allow for an excess to ensure sufficient water is available to react with the cementitious component of the mix. In drying conditions, for example in hot climates or if exposed to a drying wind, a second or further hydration may be required to ensure the GCCM meets data sheet values.

One of the key features of GCCMs is that unlike conventional concrete mixes which are very sensitive to the water-cement ratio, GCCMs cannot be over-hydrated. This is due to the fixed internal volume and control during the manufacturing process of the fill density and particle size distribution which allows the void space to be set within carefully prescribed bounds and this subsequently limits the maximum water/cement ratio achievable in the field.

This has significant benefits on site as it removes a key element of skill when preparing the concrete for application as there is no need to carefully monitor and measure the water addition. Moreover, unlike conventional concretes, GCCMs require no mixing once the water has been applied; and since the material is typically thin compared to conventional concrete (up to 13mm), it also removes the need for compaction.

1.3 *GCCM thicknesses, formats & logistics*

GCCMs are packaged, stored and delivered like many geosynthetic products, in rolled format. Since the mass per square meter is higher than most other geosynthetics, GCCMs are normally palletised rather than boom handled. Currently GCCMs are available in 3 thicknesses; 5, 8 and 13mm and come in large ‘bulk’ rolls or smaller, man-portable ‘batched’ rolls. Standard roll widths are 1.0m or 1.1m wide but have recently been made available in roll widths up to 4.4m wide.

Packaging for GCCMs is critical since the cementitious component is sensitive to moisture and the shelf-life is limited by the integrity and quality of the sealed packaging layer. When packaged correctly and stored in warehouse conditions, a shelf life in excess of 2 years can be achieved. This is substantially longer than off-the-shelf bags of cement which often have a shelf life of 6 months or less.

The ability to transport, store and deploy concrete surfacing in a roll format offers significant logistical advantages over conventional concrete solutions. A single bulk roll of 8mm GCCM can be transported on a single pallet and will surface 125sqm; and this will cover the equivalent area as two 17T ready-mix trucks using poured concrete.

There are other advantages of decoupling concrete works from the standard ready-mix concrete process aside from reduced truck movements. Being able to store large quantities of material on site for deployment at short notice removes the ‘headache’ associated with scheduling concrete pours to hit a weather window, allows for increased flexibility and reduces material wastage.

2 GCCM BENEFITS

2.1 *GCCM installation time*

GCCMs typically replace conventional concrete techniques such as poured, sprayed or precast concrete. Whilst these techniques are well established and understood, they continue to be relatively time consuming to install. GCCMs by comparison offer a step change in the installation speed of a protective concrete surface for erosion control applications. By offering the installation benefits of a rolled geosynthetic, GCCMs eliminate many of the complex and time-consuming aspects of conventional concrete such as shuttering, steelwork, floating and post-cure clean-up. An independent quantity surveyor analysis of the time benefit of GCCMs compared to conventional techniques showed time savings of the order of magnitude of up to 10 times. The time savings were even greater when used on remote sites where access for ready-mix lorries or shotcrete plant became more challenging.

Table 1. Comparison of concrete channel lining systems

Lining Material	**Installation Time Sqm/day**	**GCCM Improvement factor**
Insitu Concrete	40	10x
Precast Concrete	40	10x
Sprayed Concrete	130	3x
GCCM (8mm)	412	

*Data courtesy of Engineers Incorporated Ltd 2011.

Analysis based on a site with good road access and hence presents a worst-case situation for GCCMs when compared to conventional concrete channel lining systems.

2.2 *GCCM installation ease*

The logistical benefits of transporting GCCMs to site compared to conventional concrete methods have already been discussed in this paper. Additionally, however, GCCMs can be supplied in man-portable ‘batched’ rolls and this allows concrete infrastructure to be installed in locations previously inaccessible for conventional concrete. A rolled product format allows far greater flexibility in terms of handling and transportation, allowing panels to be cut to length off-site and then transported to the deployment area using methods appropriate to the site access conditions. This is often most appropriate for projects where GCCMs are being used as a facing for slope protection where sites can be remote and difficult to access.

Other installation benefits of GCCMs when compared to conventional concrete include:

- Reduced skill level for deployment removing the need for specialist labour
- Reduced line or lane possession due to the speed of installation and reduced need for heavy plant
- Improved site safety due to fewer truck movements and reduced need for heavy plant
- Elimination of rebound debris when used as a replacement for non-structural shotcrete
- Consistent product thickness and quality - controlled at the point of manufacture

2.3 *GCCM environmental impact*

A recent study (Mironov V. 2017 Embodied Carbon Report, Concrete Canvas) to assess the carbon footprint of a leading GCCM product using ISO 14040 full Life Cycle Assessment method, found that when considering raw materials alone a GCCM (8mm) lined channel contained less than 45% of the embodied carbon of a conventional concrete channel. Depending on the thickness utilized GCCMs typically offer a carbon saving of between 1.5 – 3.75 times.

Table 2. Raw material assessment of concrete channel lining systems to ISO 14040

Lining Material	**Kg CO2-Eq/sqm**	**GCCM Improvement factor**
ST4 Insitu Concrete (C20/24MPa) (150mm)	36.00	
GCCM (5mm)	9.59	3.75x
GCCM (8mm)	16.13	2.25x
GCCM (13mm)	24.08	1.50x

* Mironov V. 2017 Embodied Carbon Report, Concrete Canvas Ltd

When transportation was taken into consideration and based on the GCCM being transported 5 times further to site than locally sourced concrete, the GCCM still provided more than 50% reduction in transportation carbon costs.

Table 3. Transportation assessment of concrete channel lining systems to ISO 14040

Transport to Site Compaction	**Tonnes**	**Miles**	**Kg CO2-Eq/sqm**	**GCCM Improvement factor**
ST4 Concrete (C20/24MPa) (150mm)	17	20	0.44	
GCCM (8mm)	1.6	100	0.21	2.10x

* Mironov V. 2017 Embodied Carbon Report, Concrete Canvas Ltd.

3 PROPERTIES

GCCMs present a number of challenges when characterizing their properties. Like conventional geosynthetics they are flexible on deployment and like some geosynthetics (ie GCLs) they require water for activation but uniquely they transition from a flexible product into a rigid product once in service. Certain essential characteristics, such as density and thickness, need to be defined prior to deployment in the unset (uncured) state. Whilst other in-service characteristics, such as abrasion resistance, impermeability and flexural strength need to be defined in the hardened (cured) state. In addition, the hydration process needs to be carefully defined in order to ensure consistent and comparable results. This has been done through the recent publication of a ASTM D8030-16 covering sample preparation of GCCMs.

The integration of GCCMs into the geosynthetics family has been enabled by their characterization using existing geosynthetic test methods as well as the development of several new international standards. Notably the ASTM D35 committee has recently developed and published 2 new standards in addition to defining GCCM as a new class of geosynthetic material:

- ASTM D8058-17 Standard Test Method for Determining the Flexural Strength of a GCCM using a Three-Point Bending Test
- ASTM D8030M-16 Practice for Sample Preparation for GCCMs

This section of the paper aims to highlight the essential characteristics and relevant test methods for both unset (uncured) and hardened (cured) GCCMs when used in erosion control applications. Specifically, it will cover:

- Thickness & Density
- Flexural Strength
- Abrasion Resistance
- Puncture Resistance
- Durability

3.1 *Thickness & density*

A fundamental property of geosynthetic materials is their thickness and density. This provides the most basic physical data on which many other test methods depend. Conventional geosynthetic test methods such as EN 1849:2009 can be applied to characterize GCCMs in their unset (uncured) state, with samples prepared in accordance with EN 13416:2001. An example of typical GCCM thickness and mass per unit area is given below.

Table 4. Typical thickness and density properties of GCCMs

GCCM Type (nominal thickness)	**Thickness EN 1849** (mm)		**Mass per Unit Area EN 1849** (kg/sqm)
	Mean	Standard Deviation	
GCCM (5mm) – unset	4.97	0.15	7.50
GCCM (8mm) – unset	8.30	0.29	11.85
GCCM (13mm) – unset	12.33	0.35	18.99

*Data courtesy of Concrete Canvas Ltd 2017.

Results are given for GCCMs in their unset (uncured) state but the same test method (EN 1849) can also be used to record thickness and density in the hardened (cured) state.

3.2 *Flexural strength*

Tensile strength testing has long been established within the geosynthetics industry as the standard index test for evaluating geomembranes and geotextiles for the purposes of quality control, quality assurance and as a performance indicator (for durability testing for example). Whilst these test methods are applicable and appropriate for a flexible sheet product, often designed to be loaded in tension during use and whose material properties such as density, puncture resistance and durability might be linked to tensile performance; this relationship does not hold for rigid sheets products such as GCCMs

Flexural strength testing of GCCMs provides the best overall indication of the material performance in its hardened (cured) state. Fundamentally this is because the flexural strength of any rigid product is a function of both its compressive and tensile properties. Moreover, the stress-strain curve from a 3-point bend test also provides a large amount of information about how the composite layers within a GCCMs behave and interact. This can be characterized by measuring and recording 4 distinct points as shown on the graph below:

- Initial breaking load
- Initial deflection
- Final breaking load
- Final deflection

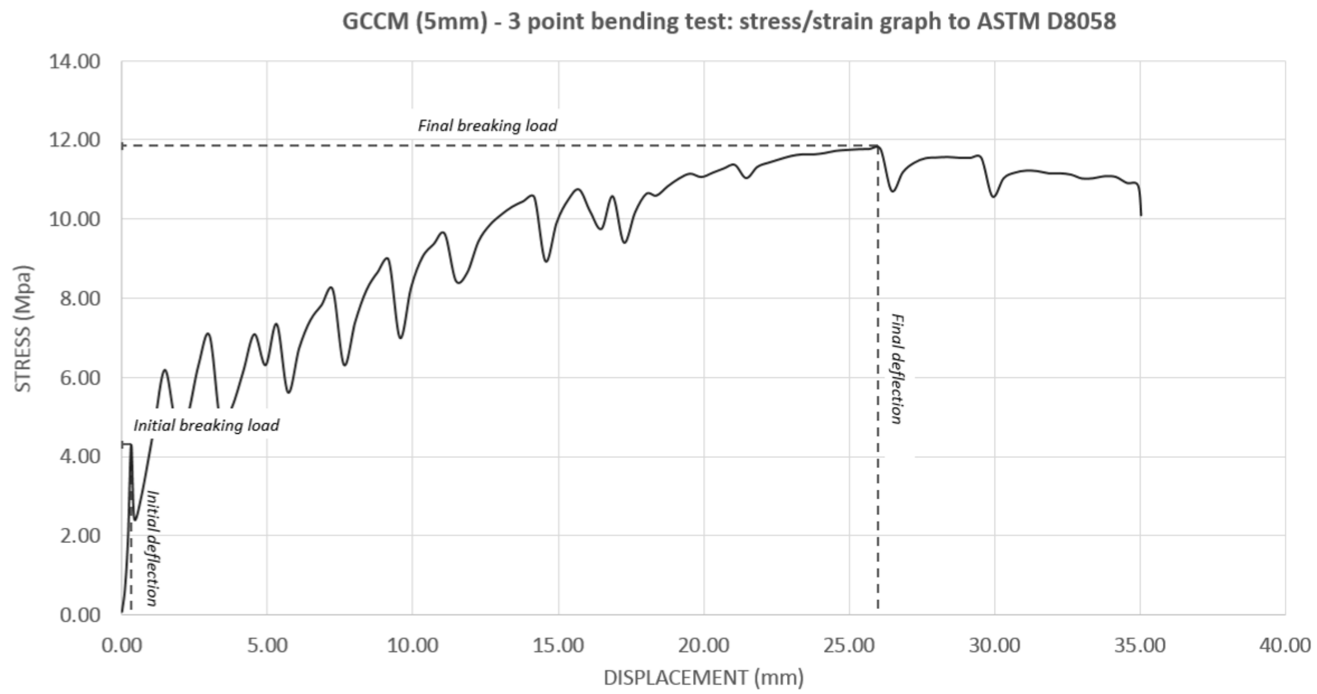

Figure 2. Typical stress-strain graph for a GCCM, data courtesy of Concrete Canvas Ltd 2017.

ASTM D8058 has recently been published which defines the test method for determining the flexural strength of GCCMs using a 3-point bend test. This is based on a test methodology that has been developed and utilised by 2 of the world's leading GCCM manufacturers for many years as part of their manufacturing quality control procedure. Whilst the test method is based on a European Norm for fibre cement sheets (EN 12467) it has been modified and updated to ensure it is appropriate for GCCMs and this test method has effectively been used within the industry since 2010.

Flexural strength testing should be used in lieu of tensile strength testing when assessing GCCMs comparative performance for properties such as chemical resistance and long term environmental durability, since it provides a better representation of the materials overall performance.

3.3 *Abrasion Resistance*

Materials used for erosion control purposes will be subject to the effects of scour, both from wind-blown particles but also more significantly sedimentation carried in surface water flow. GCCMs most common application is to line water channels both for drainage and irrigation. Their resistance to abrasion is therefore an essential characteristic when assessing their performance. Since the major contributor to abrasion resistance in GCCMs is the concrete component, there are no relevant test methods from within the existing library of geosynthetic standards. GCCM abrasion resistance is therefore best characterized using ASTM C1353-15, a simple abrasion test using a rotary platform abrader. Results are presented in terms of thickness lost (mm) per 1000 cycles.

Table 5. Typical abrasion resistance of GCCMs

GCCM Type (nominal thickness)	**Abrasion Resistance ASTM C1353-15** (mm per 1000 cycles)
GCCM (5mm)	0.15
GCCM (8mm)	0.15
GCCM (13mm)	0.15

*Data courtesy of Concrete Canvas Ltd 2017.

Figure 3. Use of a GCCM to line a tailings ditch carrying liquid made up of up to 60% solids

Abrasion could be seen to occur in 2 distinct phases, the first phase occurs as the surface fibres are worn away and the second phase when the concrete starts to become abraded. The graph below illustrates how the leading GCCM (Concrete Canvas) compares against conventional concrete. It can be seen that the surface fibres (phase 1) wear at a similar rate to 20MPa concrete; and the concrete core (phase 2) wears at a similar rate to a high compressive strength 64MPa concrete.

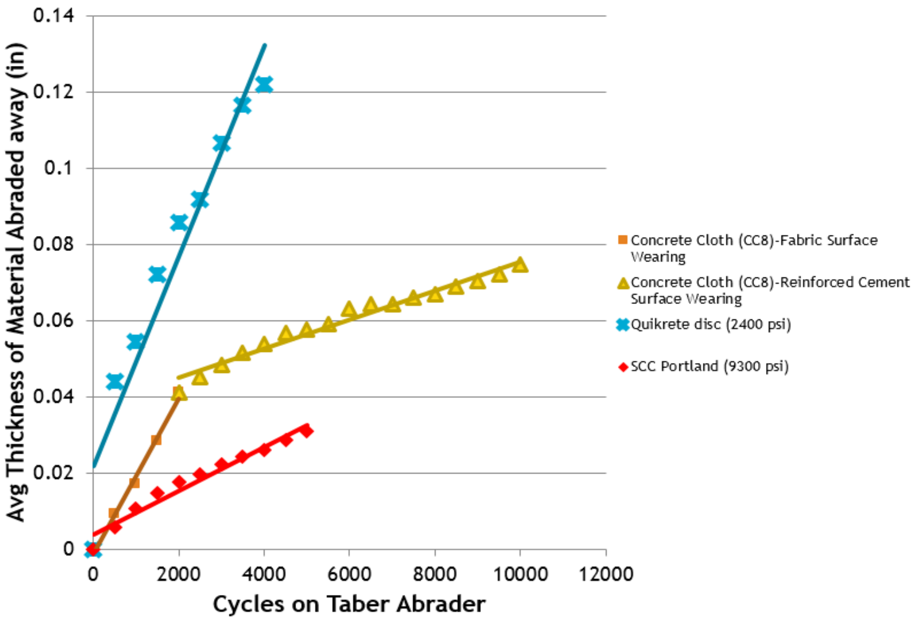

Figure 4. Two-phase abrasion resistance behavior of typical GCCM. Data courtesy of Milliken & Co 2014.

3.4 *Puncture resistance*

One of the principle features of GCCMs when compared to conventional geosynthetics is that for the majority of applications they remain exposed throughout their operational life. Whilst the polymeric liner on the rear surface provides the principle waterproofing layer in GCCMs, the concrete upper surface acts to protect this liner from the effects of abrasion (see 3.3), weathering (see 3.5) and incidental impact. Whilst many geosynthetic materials rely on being buried with top-cover to provide this protection, this needs to be an inherent feature of GCCM materials. Puncture resistance is therefore an essential characteristic when assessing the performance of GCCMs. This can be assessed using existing geosynthetic puncture test methods for both static puncture (EN ISO 12236:2006), dynamic puncture (EN ISO 13433:2006) and dynamic perforation (EN ISO 14574:2015).

Table 6. Puncture Resistance to EN ISO 12236 and EN ISO 14574

Type (nominal thickness)	**Static Puncture EN ISO 12236** Mean Ultimate	**Dynamic Perforation EN ISO 14574** Mean Ultimate
GCCB (5mm)	3.6kN	6.9kN
GCCB (8mm)	4.45kN	11.1kN

*Data courtesy of Concrete Canvas Ltd 2017.

3.5 *Durability*

The long-term durability of GCCMs is an essential characteristic in order to understand how they behave over an extended period of time when exposed to a range of environmental conditions. The composite nature of GCCMs means that both the concrete component and the polymeric component of the material must be taken into consideration. Given the thin sheet nature of GCCMs and the fact that they contain polymeric fibre reinforcement, the most relevant test method for assessing the durability of the concrete component can be obtained from within EN 12467:2012 (Fibre-cement flat sheets. Product specification and test methods) which covers environmental cyclic testing including soak-dry, freeze-thaw and heat-rain.

Table 7. Durability testing on GCCMs to EN 12467

Durability Requirement EN 12467	**Classification**	**Requirement**	**Result**
Soak-dry: 6hrs at 60(+/-5)^{O}C drying & 18hrs immersion in water >5^{O}C	Category A	50 cycles	Pass
Freeze-thaw: 1-2hrs at -20(+/-4)^{O}C freezing & 1-2hrs immersion in water 20(+/-)^{O}C	Category A	100 cycles	Pass
Heat-rain 2hrs 50mins (+/-5mins) water spray & 2hrs 50mins (+/-5mins) radiant heat	Category A	50 cycles	Pass

*Data courtesy of Concrete Canvas Ltd 2017.

The polymeric component can be assessed based on existing geosynthetic test methods, for example Annex B of EN 13254:2016 which covers a range of durability tests including weathering (EN 12224), microbiological resistance (EN 12225), leaching (EN 14415) and thermal ageing (EN 14575). When testing conventional geosynthetics the effect of these environmental conditions is assessed by change in tensile performance. As discussed in 3.2, this should be substituted for a flexural strength test as the evaluation method when testing GCCMs.

4 CONCLUSION

GCCMs are a new and exciting development within the world of geosynthetics with a broad range of applications. Their unique combination of properties means that conventional geosynthetics standards are not sufficient on their own to characterize the essential characteristics of GCCMs for erosion control applications. Standards have been utilized and adapted from existing concrete standards as well as new standards published by the ASTM D35 committee. Several material properties and test methods were identified as essential for erosion control applications and these include thickness, density, flexural strength, abrasion resistance, puncture resistance and durability.

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